Jet Propulsion Laboratory
California Institute of Technology

Mars Helicopter Technology Demonstration on Mars 2020

J. (Bob) Balaram

First *AERIAL FLIGHT* at Mars

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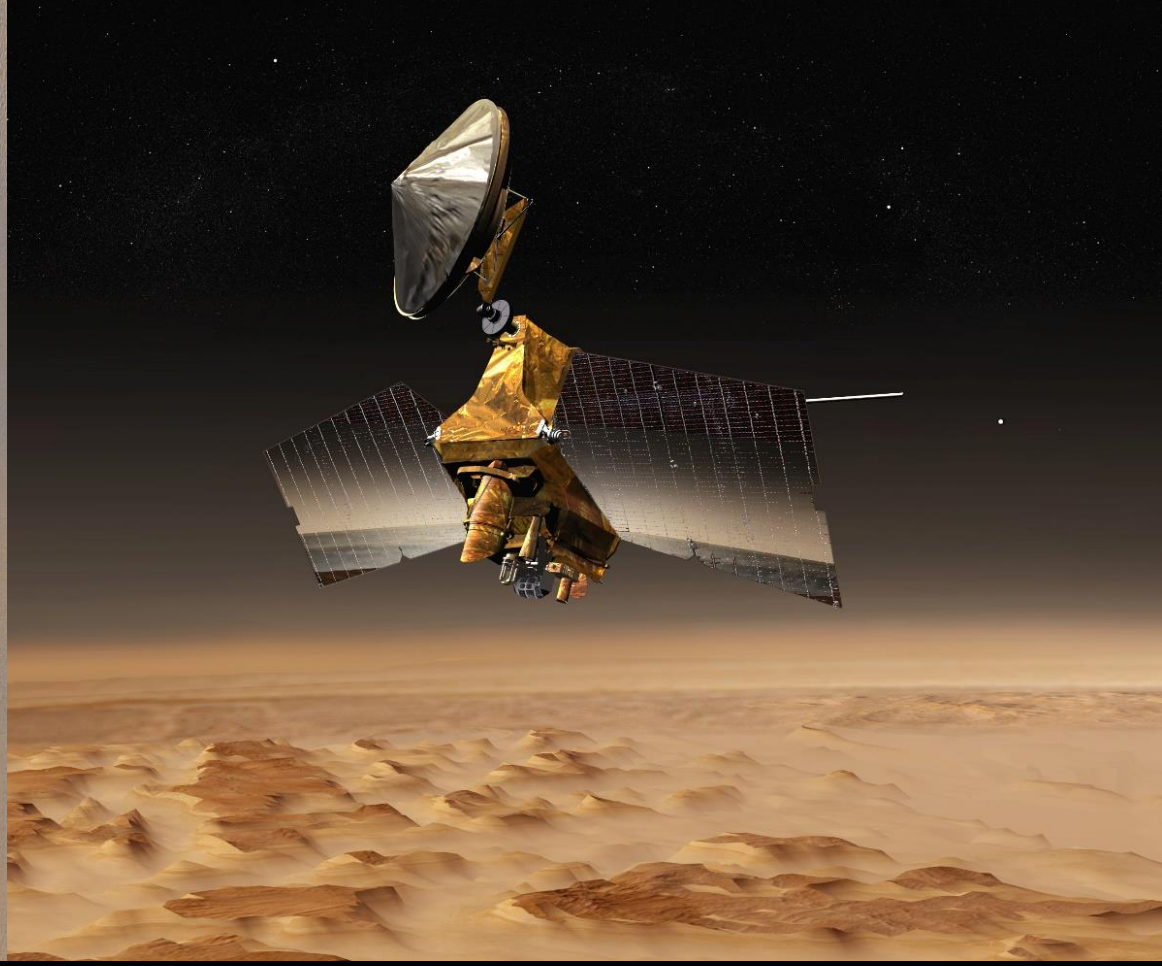


Satellites Orbiting Mars Provide Large Scale Maps…
But Finer Features Are Not Detectable

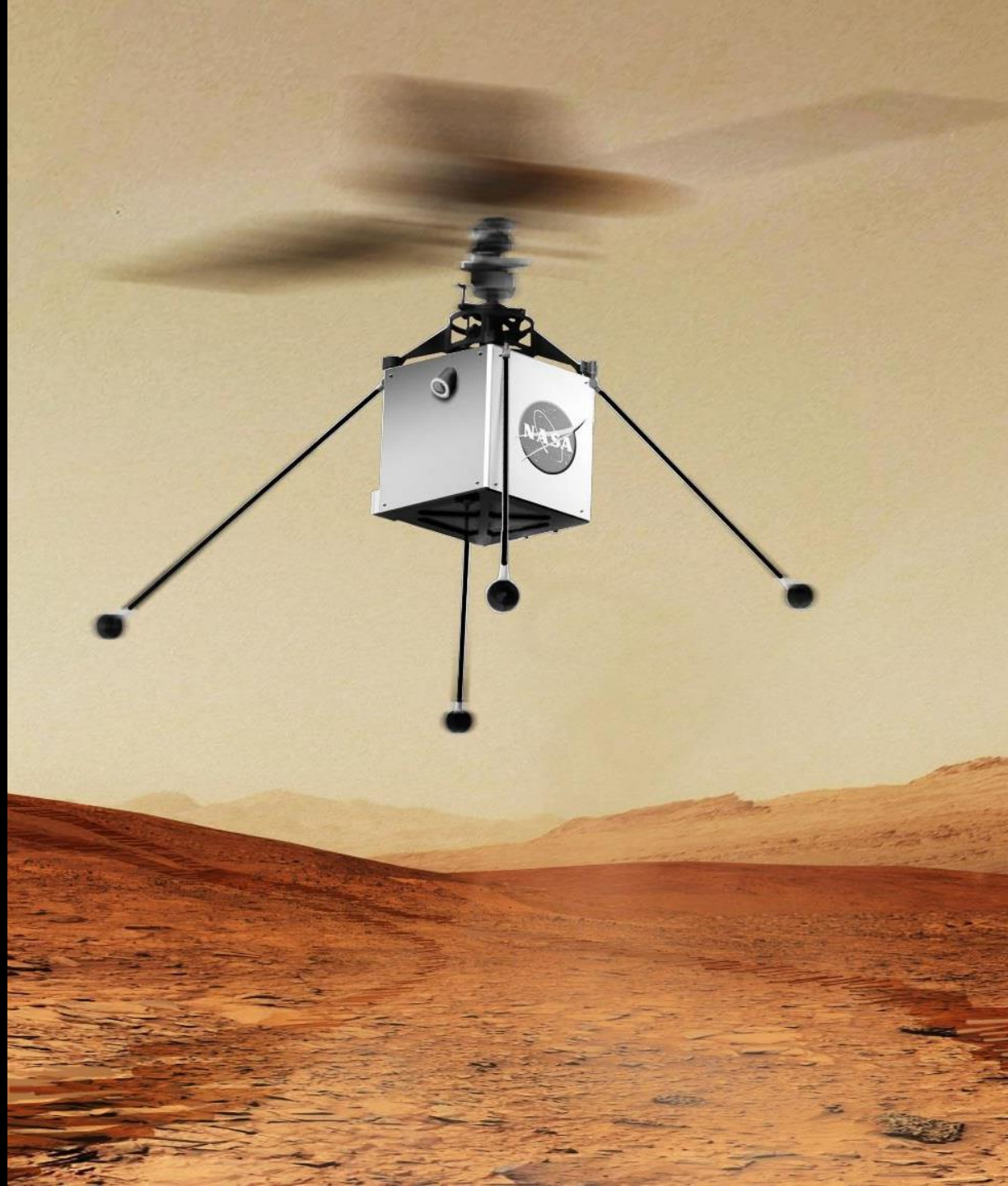
We Want High-Definition Images
and Visibility beyond Obstructed Views

We Want to Go to Locations
Inaccessible by Rovers and Humans

Adding the Aerial Dimension …

- Bridges the gap between orbital and ground-level imagery
- Scouts terrain far ahead of the rovers and humans
- Goes where it is inaccessible for the rovers or humans

So what does it take to fly a helicopter at Mars?



"Artist's Concept"

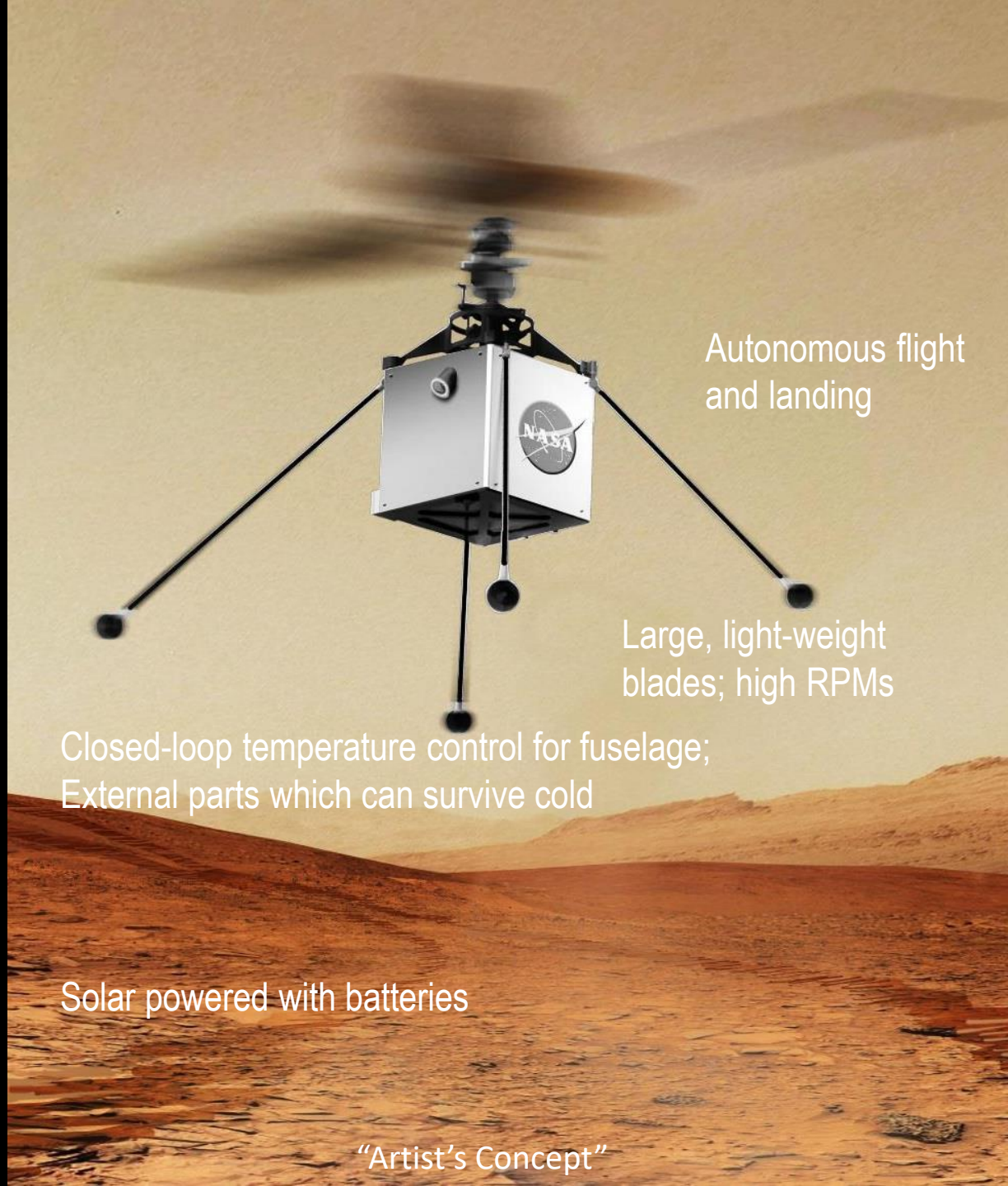
Conditions at Mars

Large distance from Earth

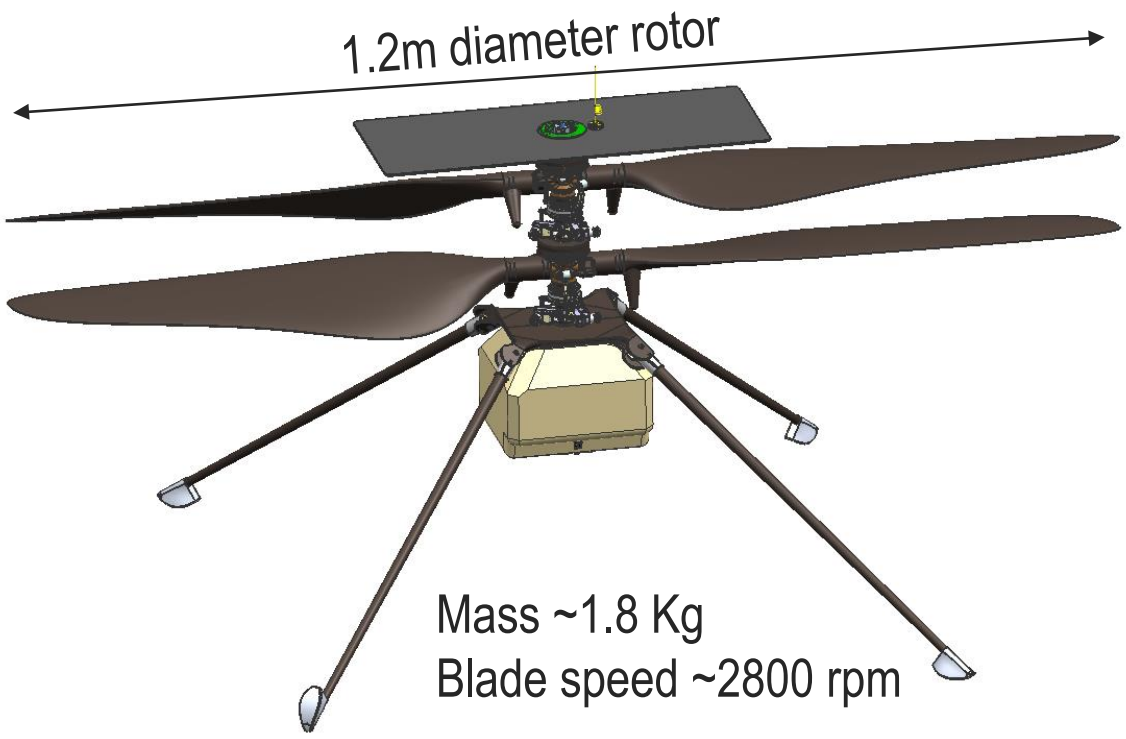
Thin atmosphere (1% of Earth's)

Cold Martian nights (~ -90ºC)

Need self-sufficient solar power system



Solution for Flight in Thin Atmosphere of Mars



- Lightweight vehicle
- Large blades
- Blade shape designed for thin atmosphere
- Blades spin at high revolutions per minute

Team

- NASA Jet Propulsion Laboratory, California Institute of Technology
- AeroVironment, Inc.
- NASA Ames Research Center
- NASA Langley Research Center

Fundamental Question

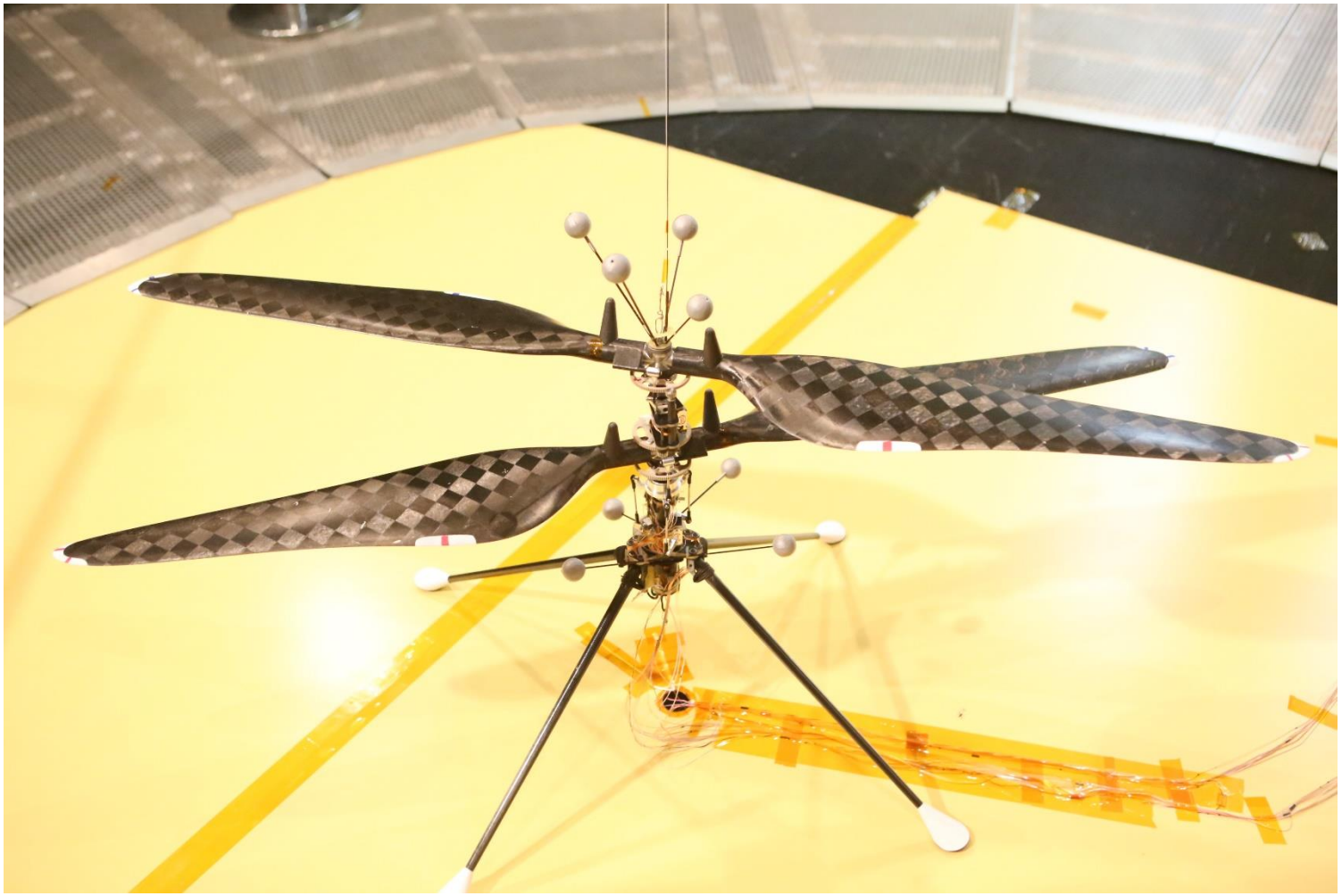
"Can one lift a helicopter in the thin Martian atmosphere?"

Demonstrated that Lift Can be Achieved in Mars-like Atmospheric Density with a 1/3-Scale Helicopter

Fundamental Question

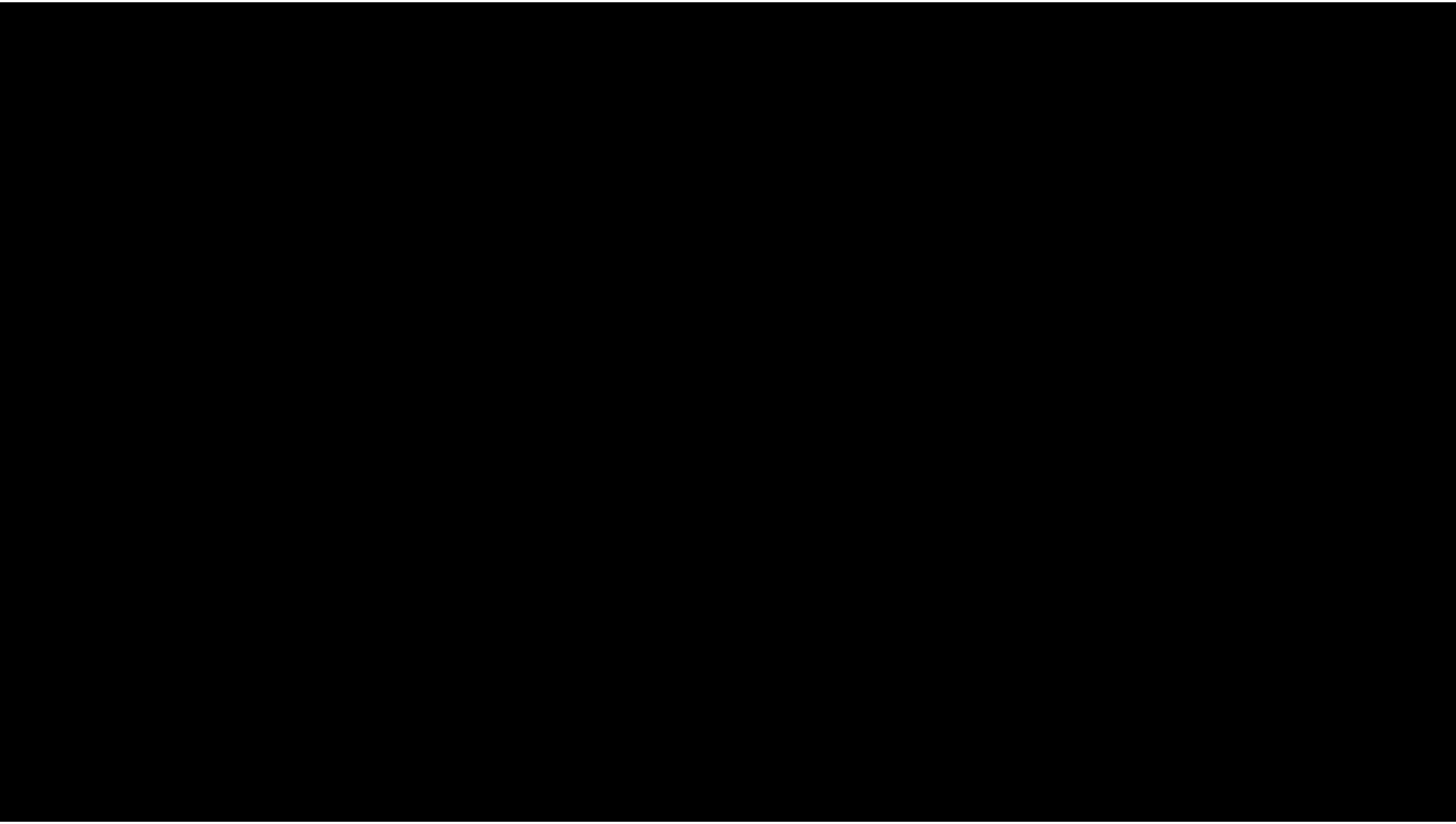
"Can one fly a helicopter in a controlled manner in Martian atmosphere?"

Built a Proof-of-Concept Helicopter



Full-Sized Rotor System (1.2m Diameter)

Demonstrated Autonomous Controlled Flight in Mars-like Atmosphere



in JPL 25-foot Space Simulator

Engineering Question

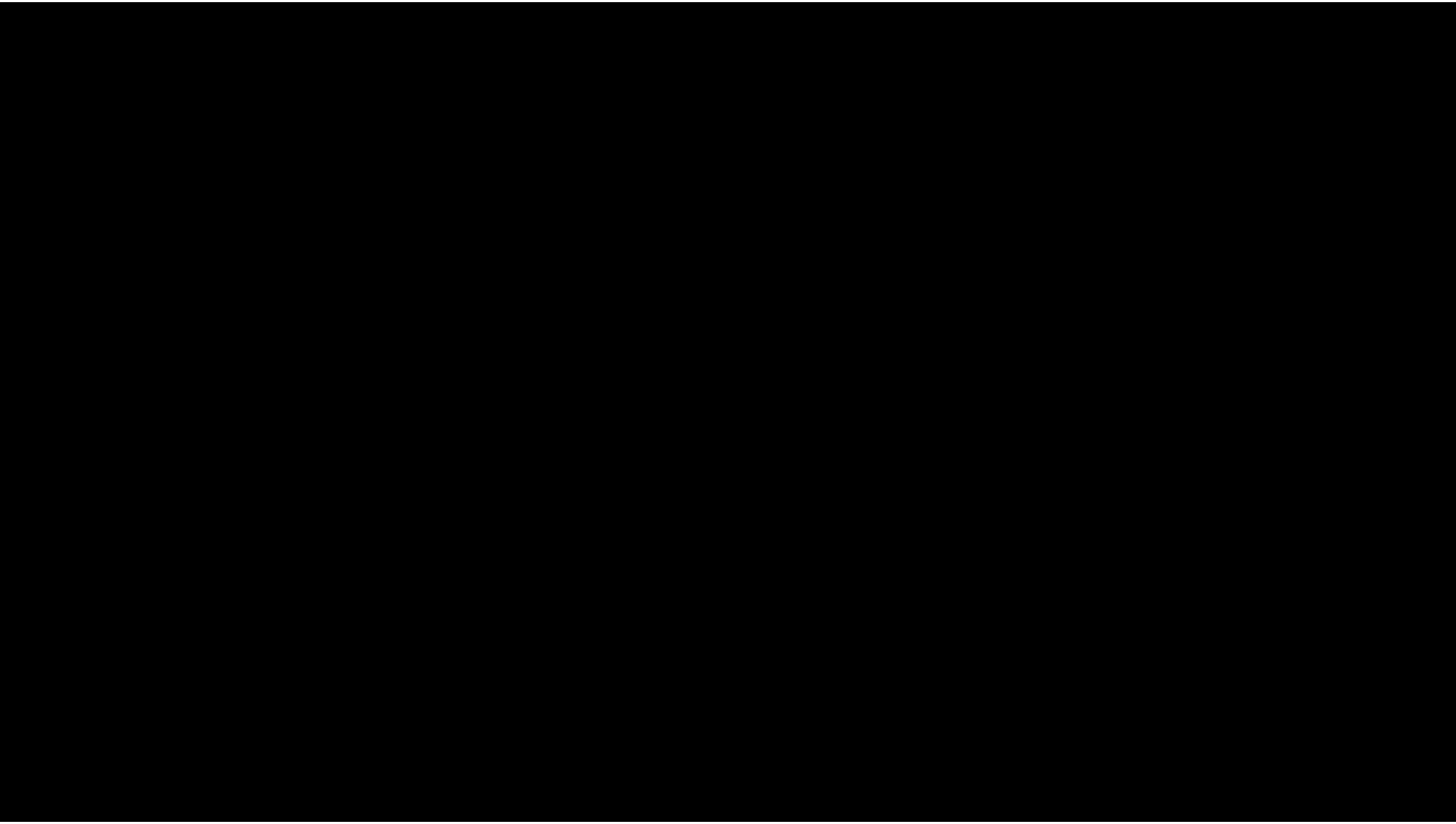
"Can one build that helicopter to survive Mars environment and operate and fly as designed?"

- *<2 Kg (to fly in Mars atmospheric density ~1% of Earth's)*

- *Contains all built-in capability needed for operation at Mars*
  - *Able to fly autonomously*
  - *Autonomously charge itself*
  - *Autonomously keep warm through the night*
  - *Communicate with Base Station on Rover*

Designed and Built
Engineering Development Model Mars Helicopter

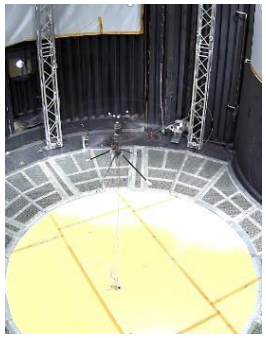
Demonstrated Flight in Mars-like Atmosphere



Engineering Development Model Mars Helicopter

Next Step

Show feasibility of Helicopter Lift at Mars	Proof-of-Concept Controlled Flight Demo	Helicopter System Design for Tech Demo Flight at Mars	Engineering Development Model Helicopter meeting Mars & Rover constraint	Flight Model Mars Helicopter	Support M2020 Test and Integration onto Rover
✓ **Completed**	✓ **Completed**	✓ **Completed**	✓ **Completed**	⬆ ***In Progress***	⬆ ***Launch***

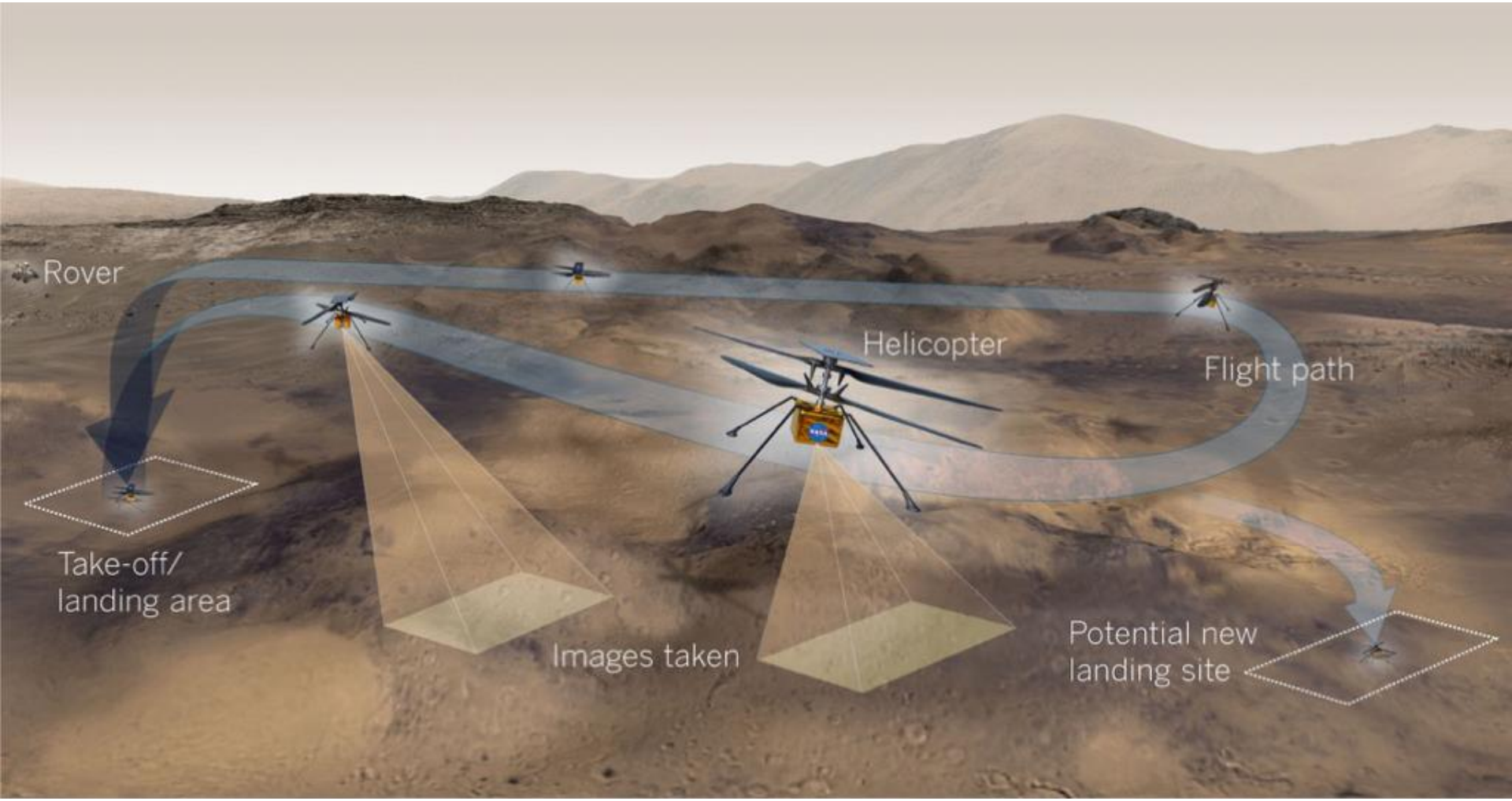


Mars Helicopter Technology Demonstration on M2020

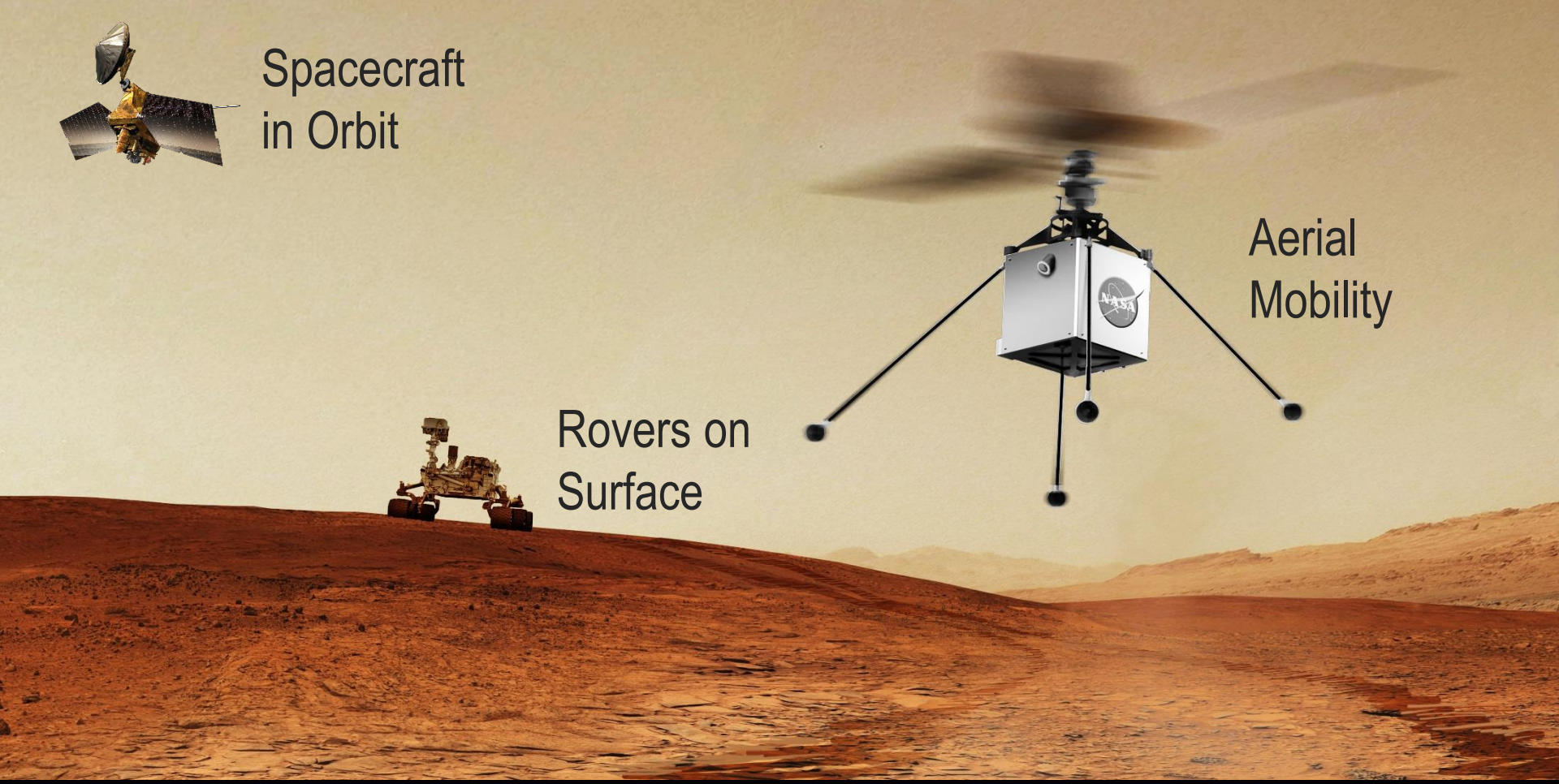
- Capable of flight in thin Mars atmosphere (10 millibar or ~1% of Earth)
- “Co-axial” Helicopter
- Blades 1.2-meter tip-to-tip
- Mass 1.8 Kg
- Solar powered - up to one 90-second flight per day
- Flight Range up to 300 m
- Heights up to 10 m
- Autonomous flight & landing
- Able to survive cold Martian nights

Expand Exploration using Aerial Mobility

Mars Helicopter Demonstration Flights at Mars

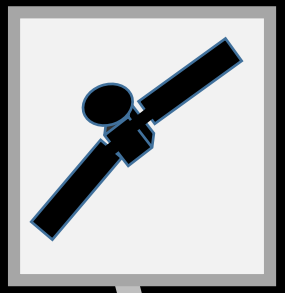


Opens Door to Future Aerial Missions



Mars Helicopter would add aerial mobility as a key element of future planetary missions

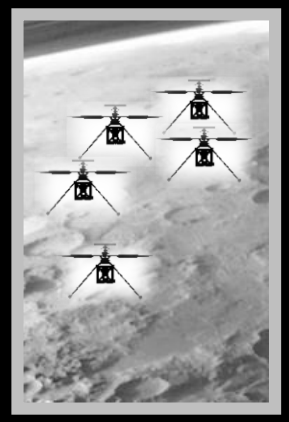
Adding Aerial Mobility Promises to Open Doors to New Classes of Exploration…



ORBITERS
Wide-Area
Lower-Resolution Imaging

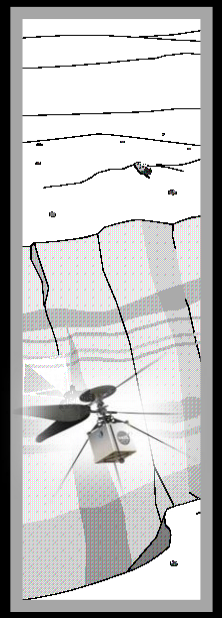
LANDERS
Single Location
No Mobility
Local High-Resolution Imaging

ROVERS
Limited Mobility
Local High-Resolution Imaging



Regional Exploration Using Multiple Helicopters

ROVER PAIRED WITH SCOUT
Efficient Mobility
Wide-Area High-Resolution Imaging



Biologically Sensitive Zone Exploration

INDEPENDENT HELICOPTER SCOUT
Long-Range Mobility
Wide-Area High-Resolution Imaging

Pre-Decisional Information –For Planning and Discussion Purposes Only

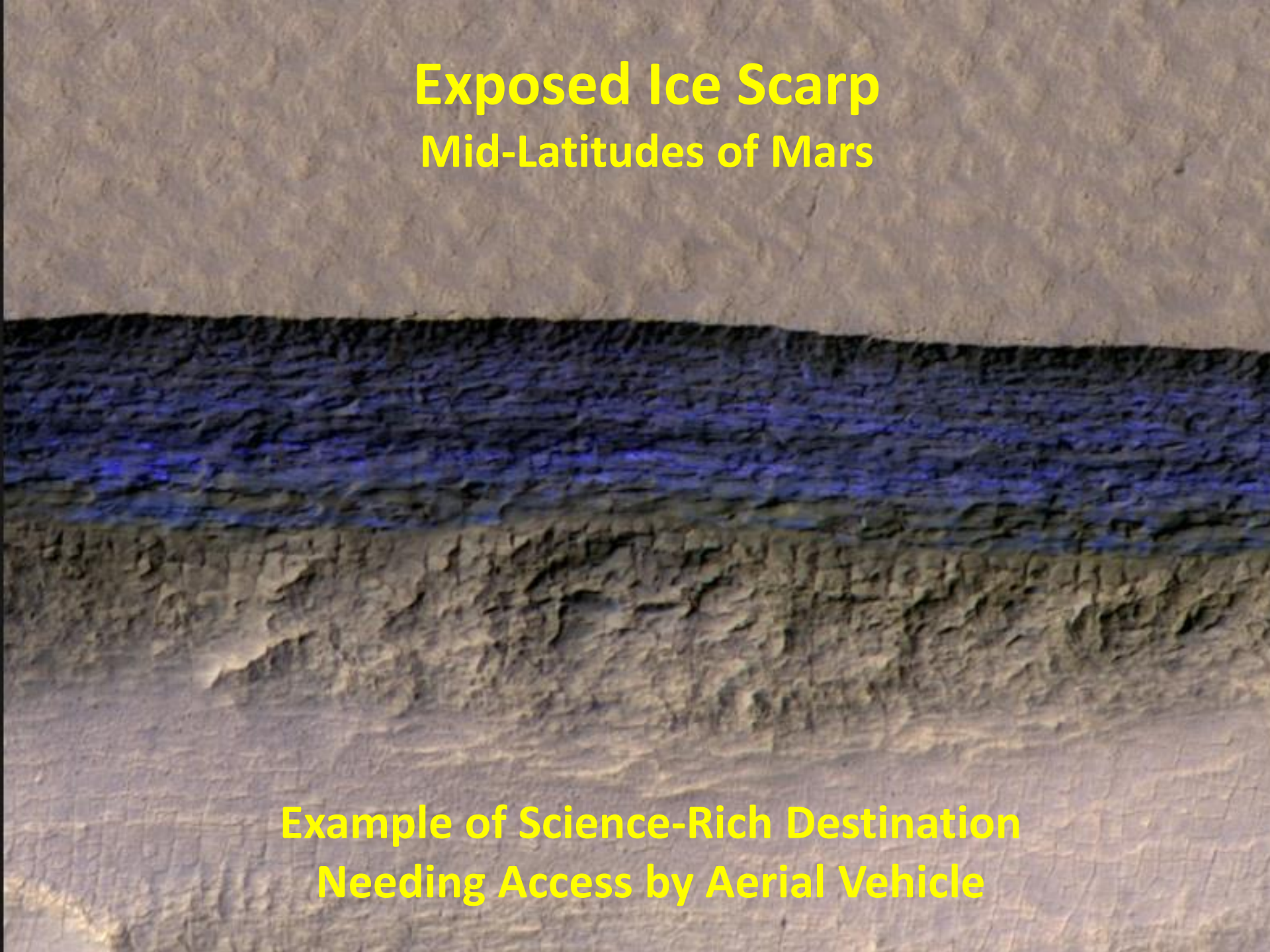
MARS HELICOPTER

- Opens doors to aerial mobility -

- 2.5Kg-class 1.2m diameter helicopter (250g camera)
- 5Kg-class 1.2m diameter helicopter (1 Kg payload: camera, point spectrometer, deposit sampling)

- ❑ Aerial mobility holds potential to open inaccessible regions of Mars to science exploration
- ❑ Future generation of small drones (2-5 kg) could:
  - Access steep terrain, cliffs, caves, steep impact craters, etc
  - Improve rover operations efficiency

Pre-Decisional Information –For Planning and Discussion Purposes Only


Exposed Ice Scarp
Mid-Latitudes of Mars
Example of Science-Rich Destination
Needing Access by Aerial Vehicle

Crater Walls

Gullys

Recurring Slope Linea

Possible Recent Water

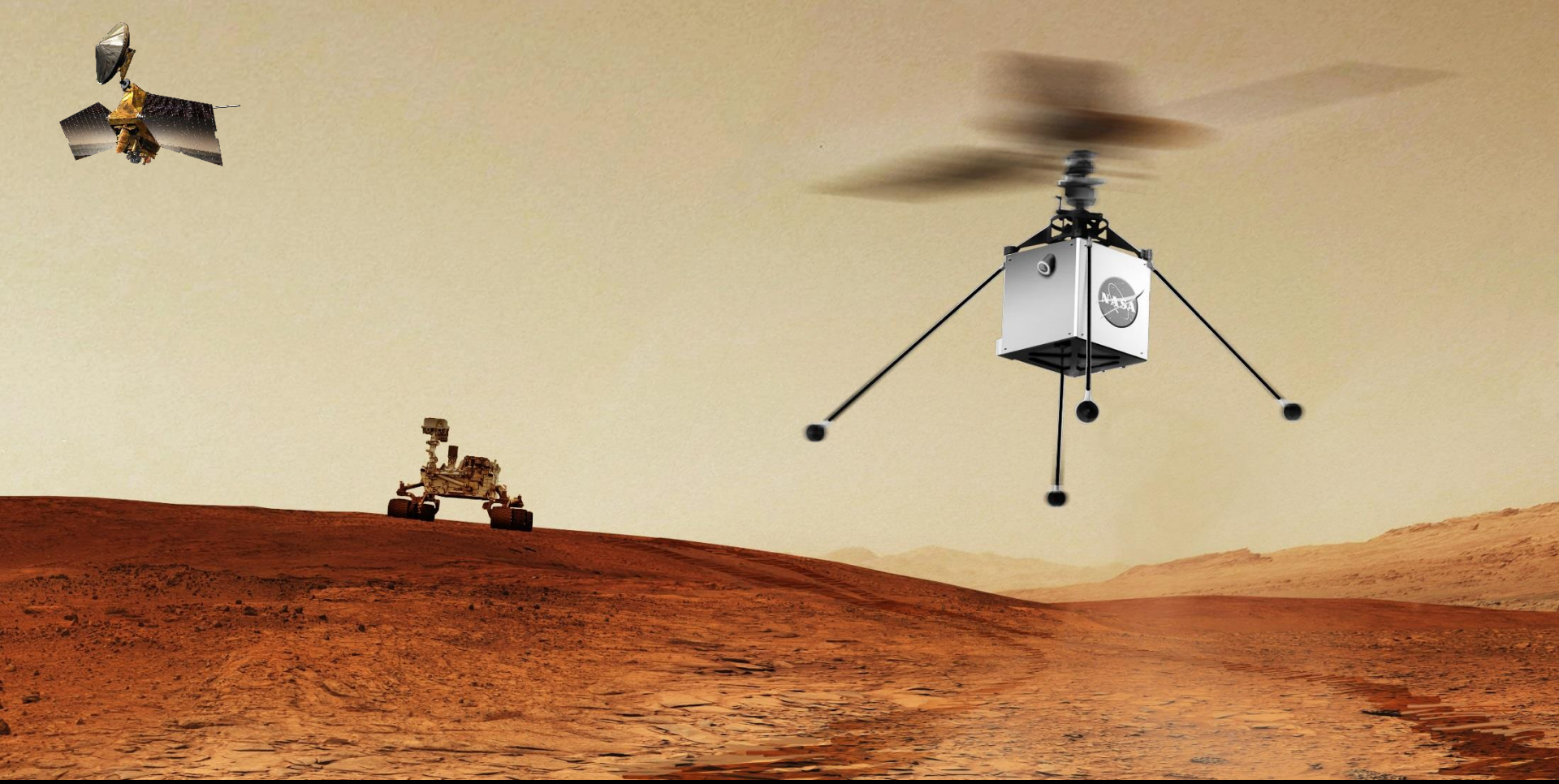
Too Steep for Rover

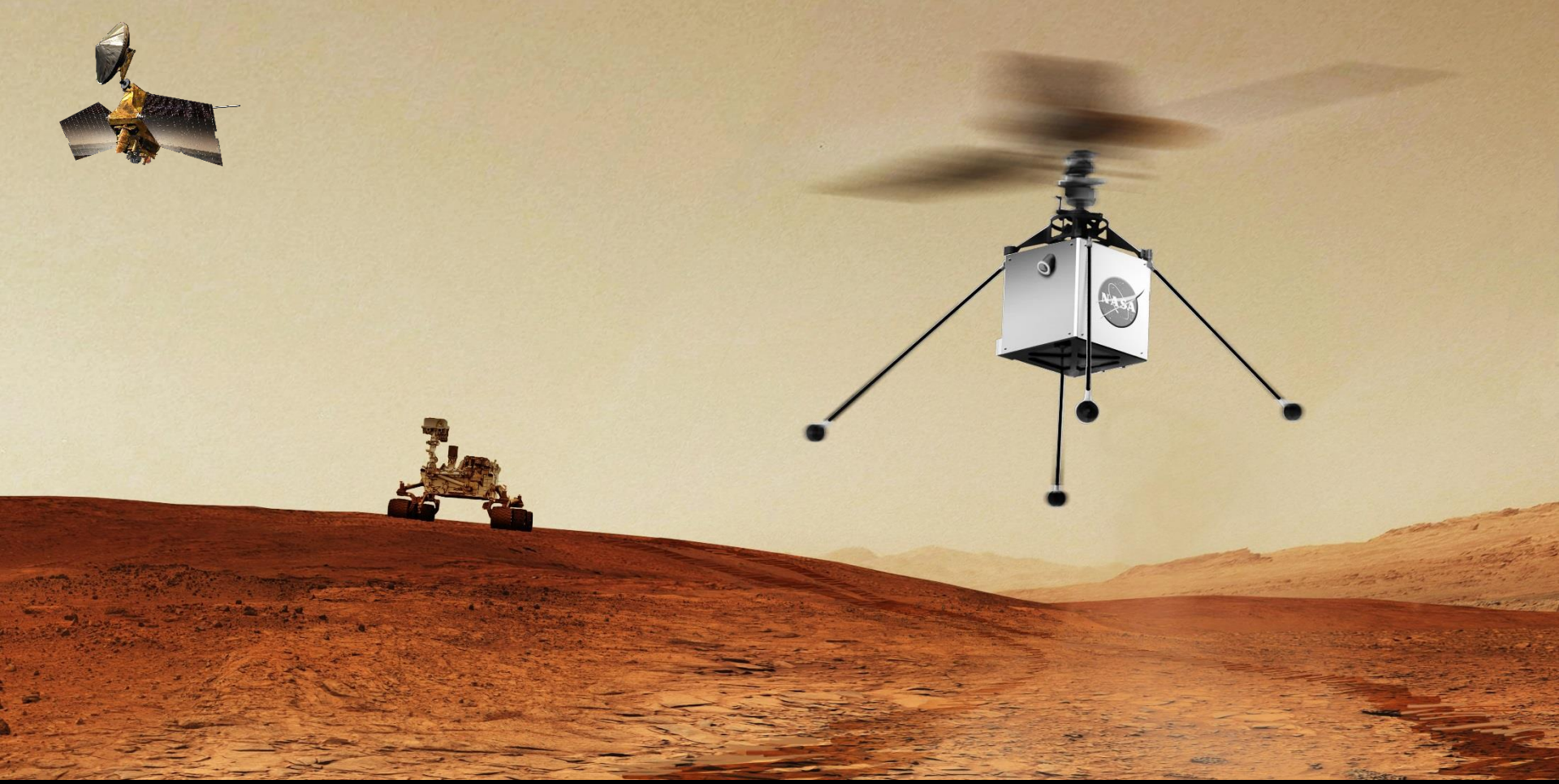
Helicopter

Image Up Close

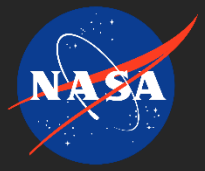
Sample Deposits

Example of a Possible Future Helicopter Mission
Accessing Areas not Reachable by Rover or Humans


NASA



Questions?



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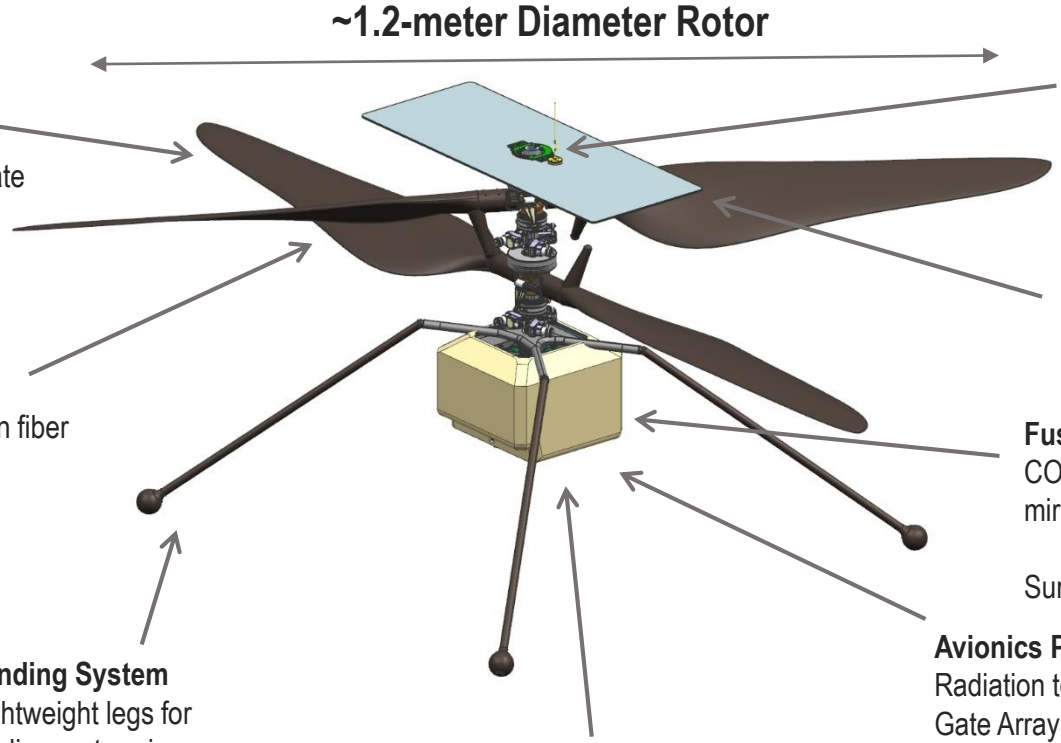
Back-Up Charts

Mars Helicopter Technology Development

- Capable of flight in thin Mars atmosphere (10 millibar or ~1% of Earth)
- “Co-axial” Helicopter
- Blades 1.2-meter tip-to-tip
- Mass 1.8 Kg
- Solar powered - up to one 90-second flight per day
- Flight Range up to 300 m
- Heights up to 10 m
- Autonomous flight & landing
- Able to survive cold Martian nights

Expand Exploration using Aerial Mobility

Technologies in a Mars Helicopter



Rotor System
Brushless motors for rotor
Brushed motors for swashplate collective / cyclic

Blades
Lightweight carbon fiber

Landing System
Lightweight legs for landing on terrain

Telecommunication
COTS chipset
Two node network
802.15.4 protocol (ZigBee)

Solar Panel
Inverted Metamorphic Quadruple Junction (IMM4) solar cells

Fuselage
CO_2 gas-gap insulation – dark mirror kapton film skin technology

Survival heaters

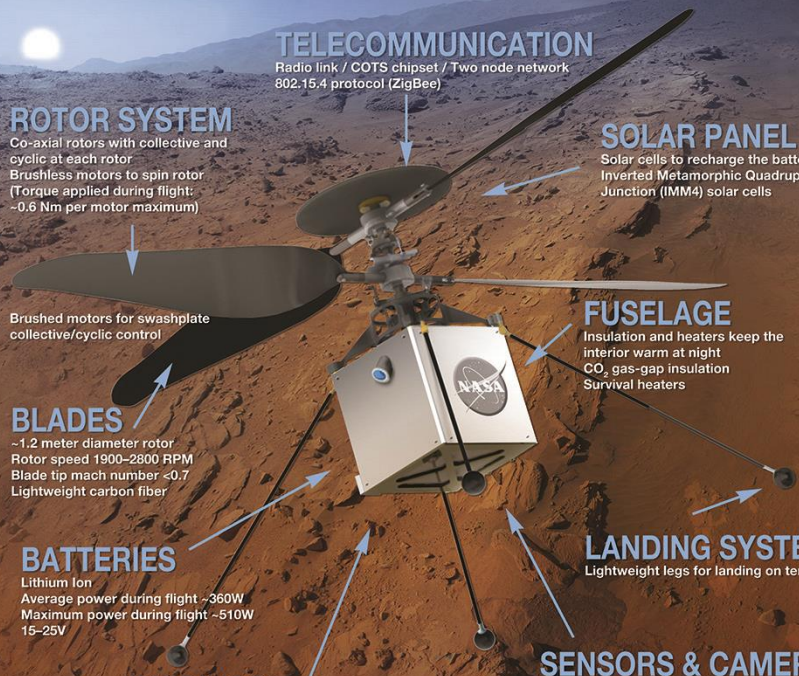
Avionics Processing
Radiation tolerant Field Programmable Gate Array (FPGA)
Dual-redundant automotive-grade processors
Navigation processor

Autonomous flight control algorithms

Sensors & Cameras
MEMS IMU
Laser Altimeter
Inclinometer
133˚x100˚ FOV Navigation camera
13 Mpixel 56˚x42˚ FOV color camera for pictures of terrain

Total Mass < 1.8 Kg
Rotor Speed: 1900-2800 RPM
Blade Tip Mach Number: < 0.7

ANATOMY OF A MARS HELICOPTER



TELECOMMUNICATION
Radio link / COTS chipset / Two node network
802.15.4 protocol (ZigBee)

ROTOR SYSTEM
Co-axial rotors with collective and cyclic at each rotor
Brushless motors to spin rotor
(Torque applied during flight: ~0.6 Nm per motor maximum)

Brushed motors for swashplate collective/cyclic control

SOLAR PANEL
Solar cells to recharge the battery
Inverted Metamorphic Quadruple Junction (IMM4) solar cells

FUSELAGE
Insulation and heaters keep the interior warm at night
CO_2 gas-gap insulation
Survival heaters

BLADES
~1.2 meter diameter rotor
Rotor speed 1900–2800 RPM
Blade tip mach number <0.7
Lightweight carbon fiber

BATTERIES
Lithium Ion
Average power during flight ~360W
Maximum power during flight ~510W
15–25V

LANDING SYSTEM
Lightweight legs for landing on terrain

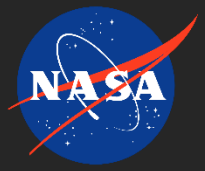
AVIONICS PROCESSING
Autonomous flight guidance, navigation & control on fault tolerant computing architecture
Autonomous flight control algorithms
Radiation tolerant field programmable dual-redundant automotive-grade processors
Navigation processor

SENSORS & CAMERAS
MEMS IMU / Laser Altimeter / Inclinometer / Accelerometers / Gyros
133° x 100° FOV navigation camera /
13 Mpixel 56° x 42° FOV color camera for pictures of the terrain

Total Mass <1.8 Kg

MARS FLIGHT ENVIRONMENT
Atmospheric density: ~1% of Earth
Reynolds Number at 0.75R: 9000 — 15000
Temperatures: -50°C to -25°C
Gravity: ~3.71 m/s2 (~40% of Earth)

National Aeronautics and Space Administration



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